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BS PAS 71 (2005) (English): Vocabulary. Nanoparticles

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PUBLICLY AVAILABLE SPECIFICATION

PAS 71:2005

Vocabulary — Nanoparticles

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Preface

It may not be customary to preface a Publicly Available Specification (PAS) but, as Director General responsible both for promoting standards activities in the UK and encouraging the development and application of key emerging technologies, I believe this PAS marks an important development in policy and that the efforts of all concerned should be recognised.

In December 2003 the DTI published the Innovation Report which set out its thinking on a more strategic approach towards the development of emerging technologies. Since then we have been implementing the report, notably in the area of technology development through a series of competitions to support the development of new technologies. But the report also set out the importance of metrology and standards in the widespread development and application of new technologies. As a result, the National Standardisation Strategic Framework (NSSF) was established.

This PAS represents the first small step in this direction in an area, nanotechnology, which many are predicting holds the key to technology, indeed, economic development over the next twenty years. It also shows how the NSSF can be a driver in developing forward looking standards which meet the needs of business in the area of emerging technologies.

Developing agreed terms and definitions may seem to be of little consequence but is fundamental to the development of a common understanding of the terms in this field. From here we can begin to address the key societal, commercial and legal issues that face the nanotechnology community today through the development of standards.

The work to date also forms the basis for wider international developments and collaboration. I am delighted at the level of international involvement in this project and that, partly as a result of this initiative, the BSI, National Physical Laboratory and the steering committee of UK experts are at the forefront of European and international efforts to establish standards in this area. To all who have been involved in this project I should like to offer my thanks and congratulations.

David Hughes

Director General Innovation Group

Department of Trade and Industry

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Foreword

This Publicly Available Specification has been developed by the Department of Trade and Industry (DTI) in collaboration with the British Standards Institution (BSI). No copying without permission of BSI except as permitted by copyright law.

Acknowledgement is given to the following organizations that were consulted in the development of this specification.

Steering Panel members:

- Health & Safety Executive (HSE)
- Institute of Occupational Medicine (IOM)
- IonBond Ltd
- Loughborough University (IPTME)
- Malvern Instruments Ltd
- National Physical Laboratory (NPL)
- QinetiQ Nanomaterials

Review Panel members:

- American Society for Testing and Materials (ASTM) Subcommittee E56.01 on Terminology & Nomenclature
- Association of British Healthcare Industries (ABHI)
- Berufsgenossenschaftliches Institut für Arbeitsschutz (BGIA), Germany
- the Casali Institute of Applied Chemistry, the Hebrew University of Jerusalem
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- the University of Manchester
- VDI Technologiezentrum GmbH
- Weizmann Institute of Science, Israel
- University of Leeds

BSI/CEN/ISO Committees:

- EPL/76 Optical radiation safety and laser equipment
- IST/34 Automatic Identification & Data
- LBI/37 Sieves, screens and particle sizing
- RPI/1 Refractory Products & Materials
- RPI/13 Advanced Technical Ceramics
- NTI/1 Nanotechnologies
- STI/40 Thermally Sprayed Inorganic Films
- TC187 Refractories
- TCI/24 Physical testing
- TCI/63 Burning behaviour
- TCI/66 Apparel and indoor textiles
- TCI/69 Leather and footwear
- TCI/69/1 Coated fabrics
- TCI/80 Chemical testing
- WEE/46 Non-destructive testing
- CEN/BT/WG/166 Nanotechnologies
- ISO/TC33 Refractories
- ISO/TC146/SC2/WG1 Particle size selective sampling and analysis (workplace air quality)

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Introduction

This Publicly Available Specification (PAS) has been commissioned by the UK Department of Trade and Industry (DTI) for the purposes of developing and encouraging the use of a common language for nanoparticle technologies. Nanotechnology is an emergent technology that is developing quickly and will gain increasing importance over the next 20 years. This PAS is intended to seed further developments and discussions in formal standards making and inform the production of other nanotechnology standards.

The market sector of nanoparticle technologies is of current interest to the general nanotechnology community both in the UK and internationally and has been the subject of much discussion in recent years. This PAS was commissioned partly in response to demands by UK industry to lay down standards for the future. The intention is to bring together the current disparate vocabularies of nanoparticle technologies. The main difference between a PAS and a full British, European or International Standard, is that a PAS is created in a consultative process across industry rather than gaining the full consensus of a selected technical committee. This PAS will be withdrawn once it is superseded by a full consensus document on the subject. Until then it will be updated at regular intervals to cover new developments in the field.

The remit of this PAS is to document and, to a lesser degree, comment on the current use of basic nanoparticle terms and definitions in current use by manufacturers, suppliers, academia, regulators and governments and to give recommendations for usage as required. It also includes terms defining common production methods and analytical techniques currently employed by those working with nanoparticles.

It does not cover nomenclature systems for nanoparticle or fullerene-based materials, as this is a highly specialized subject and there is no current consensus in the nanotechnology or nanoscience community on how to approach such a system.

There remain areas of terminology where confusion between researchers, developers and users of nanoparticles have arisen; these could be greatly reduced by adopting the following good practice:

Ambiguous terminology: due to the interdisciplinary nature of nanotechnologies, the definition of some technical terms might be different for those with backgrounds in different science or engineering fields and industry sectors. Whilst this PAS aims to provide a single definition for each term, there were some terms that had more than one widely used meaning. When using a term for which this vocabulary shows more than one meaning, it is recommended that qualifying information as to which meaning is intended is stated.

Means of determination: many of the measurable parameters of nanoparticles can be experimentally determined by more than one technique. These techniques can be based on fundamentally different processes, require differing degrees of interpretation or lead to different results. When such information is communicated, in addition to any normally reported degree of confidence or data distribution that may be quoted, it is recommended that the means by which the information was derived/determined is stated.

Thanks are due to the leading UK and international nanotechnologists involved in the development and review of this PAS for enabling it to be produced in a timely manner.

1 Scope

This Publicly Available Specification lists terms and definitions currently in use in the field of nanoparticles. It is intended to facilitate communications between organizations and individuals in industry and those who interact with them. This document does not include a nomenclature system for nanoparticles.

2 General terms

2.1

nanomaterial

material with one or more external dimensions, or an internal structure, on the **nanoscale**, which could exhibit novel characteristics compared to the same material without **nanoscale** features

NOTE Novel characteristics might include increased strength, chemical reactivity or conductivity.

[PAS 71 Steering Group]

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2.2
nanoparticle
particle with one or more dimensions at the **nanoscale**

[PAS 71 Steering Group]

NOTE 1 Also referred to as nanoparticulate, although this term is more often used adjectivally.

NOTE 2 Novel properties that differentiate **nanoparticles** from the bulk material are typically developed at a critical length scale of under 100 nm.

2.3
nanoscale
having one or more dimensions of the order of 100 nm or less

NOTE Also referred to as nanosize.

[PAS 71 Steering Group]

2.4
nanoscience
study of phenomena and manipulation of materials at atomic, molecular and macromolecular scales, where properties differ significantly from those at a larger scale

[*Nanoscience and nanotechnologies* [1]]

2.5
nanostructured
having a structure at the **nanoscale**

NOTE **Agglomerate**s and **aggregate**s of **nanoparticle**s are examples of nanostructured particles.

[PAS 71 Steering Group]

2.6
nanotechnology
design, characterization, production and application of structures, devices and systems by controlling shape and size at the **nanoscale**

[*Nanoscience and nanotechnologies* [1]]

3 Particle names: generic

3.1
acicular particle
needle shaped particle

[BS 2955:1993, *Glossary of terms relating to particle technology*]

3.2
agglomerate
group of particles held together by relatively weak forces, including van der Waals forces, electrostatic forces and surface tension

[*Occupational Ultrafine Aerosol Exposure Characterization and Assessment* [2]]

strongly bonded **aggregate**

[IUPAC *Compendium of Chemical Terminology* [3], 1991, 63, 1231]

group of strongly associated particles that cannot easily be re-dispersed by mechanical means

[PAS 71 Steering Group]

NOTE 1 It is recommended that when the term agglomerate is used that it be specified whether the bonding is strong (where elements require chemical as well as physical means for separation) or weak (where only physical means are required).

NOTE 2 Attention is drawn to the inconsistent definitions listed here for this term, which reflect the different uses of this term according to the industry context.

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3.3
aggregate
heterogeneous particle in which the various components are not easily broken apart

[*Occupational Ultrafine Aerosol Exposure Characterization and Assessment* [1]]

<from catalysis> assemblage of **primary particle**s exhibiting an identifiable collective behaviour (e.g. chemical nature of the aggregated **primary particle**s, texture of the aggregate, resistance to mechanical separation upon grinding)

NOTE 1 Strongly bonded aggregates are called **agglomerate**s.

NOTE 2 The definition of **primary particle** used is that from reference [2].

[Adapted from [3] by PAS 71 Steering Group]

weakly associated group of particles that can be re-dispersed by mechanical means

[PAS 71 Steering Group]

NOTE 3 Attention is drawn to the contrasting definitions listed here for this term, which reflect the different uses of this term according to the industry context.

3.4
bulk nanoparticles
nanoparticles produced by industrial-scale processes

NOTE Examples include **carbon black**, titanium dioxide and **fumed silica**.

[PAS 71 Steering Group]

3.5
dendrimer
synthetic, three-dimensional macromolecule built up from a monomer, with new branches added in a step-by-step fashion until a symmetrical branched structure is created

NOTE Where there is perfect branching, the particle is referred to as a dendrimer; where the branching is imperfect, it is referred to as hyperbranched.

[PAS 71 Steering Group]

3.6
dendritic particle
particle with a highly branched structure

NOTE 1 Similar to **nanostructured** material, i.e. **agglomerate**s or **aggregate**s.

NOTE 2 Also referred to as a branched-chain aggregate.

[PAS 71 Steering Group]

3.7
engineered nanoparticles
nanoparticles manufactured to have specific properties or a specific composition

[PAS 71 Steering Group]

3.8
floc
<in a liquid> assemblage of particles, which, having been initially dispersed, have become loosely coherent

NOTE Also referred to as flocc and flocculate.

[BS 2955:1993, *Glossary of terms relating to particle technology*]

3.9
fume
cloud of airborne particles, including **nanoparticles** of low volatility, arising from condensation of vapours from either chemical or physical reactions

[PAS 71 Steering Group]

3.10
fumed powder
powder recovered from a fume

[BS 2955:1993, *Glossary of terms relating to particle technology*]

3.11
incidental nanoparticles
nanoparticles formed as a by-product of man-made or natural processes, e.g. welding, milling, grinding or combustion

[PAS 71 Steering Group]

3.12
milled powder
powder produced by **comminution** in a mill

[BS 2955:1993, Glossary of terms relating to particle technology]

3.13
nanocluster
group of atoms or molecules whose largest overall dimension is typically in the range of a few nanometres

[PAS 71 Steering Group]

3.14
nanocore
central part of a **nanoparticle** encapsulated (or coated) in a dissimilar **nanomaterial**

[PAS 71 Steering Group]

3.15
nanocrystal
nanoscale solid formed with a periodic lattice of atoms, ions or molecules

[PAS 71 Steering Group]

3.16
nanopowder
dry **nanoparticles**

[PAS 71 Steering Group]

3.17
nanofibre
nanoparticle with two dimensions at the **nanoscale** and an **aspect ratio** of greater than 3:1

NOTE Types of nanofibres include nanowhiskers, nanorods and nanowire.

[PAS 71 Steering Group]

3.18
nanohorn
nanoscale cone with a curved axis

[PAS 71 Steering Group]

3.19
nano-onion
nanoparticle composed of concentric molecular shell structures

NOTE Also referred to as a nested **nanoparticle**.

[PAS 71 Steering Group]

3.20
nanoribbon
nanofibre with an approximately rectangular cross-section, where the ratio of the longer to the shorter dimensions of the cross-section is greater than 2:1

NOTE Also referred to as a nanobelt.

[PAS 71 Steering Group]

3.21
nanorod
straight solid **nanofibre**

[PAS 71 Steering Group]

3.22
nanorope
nanofibres in a twisted conformation

[PAS 71 Steering Group]

3.23
nanotube
hollow **nanofibre**

[PAS 71 Steering Group]

3.24
nanowire
conducting or semi-conducting **nanofibre**

[PAS 71 Steering Group]

3.25
primary particle
smallest identifiable subdivision in a particulate system

[*Particle Size Characterization* [4] and *The Use of Nomenclature in Dispersion Science and Technology* [5]]

particle introduced into the air in a solid or liquid form, or formed through nucleation from the vapour phase

[*Occupational Ultrafine Aerosol Exposure Characterization and Assessment* [2]]

NOTE Attention is drawn to the inconsistent definitions listed here for this term, which reflect the different uses of this term according to the industry context.

3.26
quantum dot
nanoscale particle that exhibits size-dependent electronic and optical properties due to quantum confinement

[*Occupational Ultrafine Aerosol Exposure Characterization and Assessment* [2]]

3.27
secondary particle
particle formed through **aggregation** or **agglomeration** of primary particles

[PAS 71 Steering Group]

particle formed through chemical reactions in the gas phase (gas to particle conversion)

[*Occupational Ultrafine Aerosol Exposure Characterization and Assessment* [2]]

NOTE Attention is drawn to the inconsistent definitions listed here for this term, which reflect the different uses of this term according to the industry context.

3.28
ultrafine particle
nanoparticle

NOTE This is a variant in common use by those dealing with industrial products and air pollution measurement.

[PAS 71 Steering Group]

4 Particle names: chemically specific

4.1
carbon black
… elemental carbon in the form of near-spherical particles with major diameters less than 1 µm, generally coalesced into **aggregate**s

[ISO 1382:2004, *Rubber — Vocabulary*]

4.2
carbon nanotube
nanotube consisting of one or several **graphene** sheets rolled up into a seamless tube, forming a single- or multi-walled tube

[Frost & Sullivan [6]]

NOTE Can be either a single-wall carbon nanotube (SWCNT), comprising a single layer of carbon atoms (single molecule) arranged in a cylinder, or a multi-wall nanotube (MWNT), comprising multiple concentric tubes with diameters significantly greater than a SWCNT.

4.3
fullerene
any closed-cage structure having more than twenty carbon atoms consisting entirely of three-coordinate carbon atoms

[*J. Chem. Inf. Comp. Sci.* [7], *35*, 969-978]

NOTE Also referred to as buckyball and buckminsterfullerine.

4.4
fumed silica
bulk powdered form of silicon dioxide produced from thermal pyrolysis, which could have **primary particle**s sized at the **nanoscale**

NOTE The definition of **primary particle** used is that from reference [2].

[PAS 71 Steering Group]

4.5
graphene
individual layers of carbon atoms arranged in a honeycomb-like lattice, found in graphite, a crystalline form of carbon

[Dictionary and Atlas of Nanoscience and Nanotechnology [8]]

4.6
inorganic fullerene-like material (IFLM)
nanoparticle with a layered **fullerene**-like structure but composed of non-carbon atoms

[*J. Chem. Edu* [9], 81, 673-676]

4.7
inorganic nanotube
nanotube composed of non-carbon atoms

[*J. Chem. Edu* [9], 81, 673-676]

5 Nanoparticle systems

5.1
aerosol
metastable suspension of solid or liquid particles in a gas; particles generally occur within the range of less than 1 nm to greater than 100 μm in diameter

[*Occupational Ultrafine Aerosol Exposure Characterization and Assessment* [2]]

5.2
aerosol, accumulation
associated with **coalescence** or **coagulation** of particles within the nucleation range into larger particles; distribution modes typically extend from 50 nm to 1 μm, but are not confined to these limits

[*Occupational Ultrafine Aerosol Exposure Characterization and Assessment* [2]]

5.3
aerosol, nucleation
aerosol dominated by particle formation from the gas phase, such as through nucleation from a supersaturated vapor; distribution modes typically extend from less than 1 nm to 50 nm, but are not confined to these limits

[*Occupational Ultrafine Aerosol Exposure Characterization and Assessment* [2]]

5.4
colloid
substance consisting of particles not exceeding 1 μm dispersed in a fluid

[BS 2955:1993, *Glossary of terms relating to particle technology*]

5.5
heterodisperse system
bulk powder or suspension containing particles with a range of sizes

[BS 2955:1993, *Glossary of terms relating to particle technology*]

5.6
homogenous suspension
suspension in which the particles are uniformly distributed

[BS 2955:1993, *Glossary of terms relating to particle technology*]

5.7
hydrosol
sol in which water forms the dispersion medium

[*The Use of Nomenclature in Dispersion Science and Technology* [5]]

5.8
monodisperse system
bulk powder or suspension containing **primary particle**s with a very narrow size distribution

NOTE The definition of primary particle used is that from reference [2].

[PAS 71 Steering Group]

5.9
nanocomposite
composite in which at least one of the phases has at least one dimension on the **nanoscale**

[*Pure and Applied Chemistry* [10], pp 1985–2007]

5.10
nanophase
discrete phase, within a material, which is at the **nanoscale**

[PAS 71 Steering Group]

5.11
organosol
sol in which an organic liquid forms the dispersion medium

[*The Use of Nomenclature in Dispersion Science and Technology* [5]]

5.12
sol
liquid dispersion containing particles of colloidal dimensions

[*The Use of Nomenclature in Dispersion Science and Technology* [5]]

5.13
ultrafine aerosol
aerosol consisting predominantly of ultrafine particles

[*Occupational Ultrafine Aerosol Exposure Characterization and Assessment* [2]]

NOTE Also referred to as nanoaerosol.

6 Production methods

6.1
atomization
technique sometimes used for producing solid particles by dispersion of molten material, solution or suspension sprayed under conditions such that it breaks down and then solidifies or dries as a finely divided powder or aerosol

NOTE 1 Typically used to make particles down to a size of 2 µm, i.e. larger than **nanoscale**.

NOTE 2 Also referred to as nebulization.

[PAS 71 Steering Group]

6.2
attrition
form of **comminution**, where reduction in size is caused by erosion resulting from the collision of particles with other particles or surfaces

[PAS 71 Steering Group]

NOTE Also referred to as ultrafine grinding and nanosizing.

6.3
bottom-up processing
additive process to create nanostructures from atoms and molecules

[PAS 71 Steering Group]

6.4
calcination
producing or modifying powder by heating to a high temperature in a dry environment

[PAS 71 Steering Group]

6.5
chemical vapour synthesis
production method where vapour is formed in a reaction chamber by, for example, pyrolysis, reduction, oxidation or nitridation and condenses to form particles

NOTE 1 Also referred to as chemical vapour growth.

NOTE 2 One application is the synthesis of carbon **nanotube**s.

[PAS 71 Steering Group]

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6.6
colloidal production methods
established wet chemistry precipitation processes, also used to produce **nanoparticles**, in which solutions of different ions are mixed under controlled conditions of temperature and pressure to form insoluble precipitates, which can remain in liquid suspension for distribution and use, or may be used as slurries or collected by filtering or spray drying to produce a dry powder

[*Nanoparticles: An occupational hygiene review* [11]]

6.7
comminution
reduction of particle size by fracture

[BS 2955:1993, *Glossary of terms relating to particle technology*]

NOTE See also **attrition**.

6.8
electro-explosion
process for the production of **nanoparticle**s whereby a wire is fed into a reactor, and subjected to a high-current, high-voltage microsecond pulse to cause it to explode

[Adapted from *Nanosized Alumina Fibers* [12] by PAS 71 Steering Group]

NOTE Also referred to as exploding wire aerosol generation.

6.9
electrohydrodynamic atomization
technique able to produce monodisperse droplets of a defined size in the micrometer range: liquid is supplied to a nozzle, and an electric field generated between the nozzle and a counterelectrode; when the electrical stress overcomes the surface tension of the liquid, a cone is formed, from which a thin jet emerges, which breaks up into monodisperse droplets

[American Physiological Society [13]]

6.10
electrospinning
fabrication process using an electric field to control the deposition of polymer **nanofibre**s onto a target substrate

[PAS 71 Steering Group]

6.11
Electrostatic Spray Assisted Vapour Deposition (ESAVD)
production method involving spraying atomized precursor droplets across an electric field where the droplets undergo combustion and chemical reaction in the vapour phase

[PAS 71 Steering Group]

6.12
flame pyrolysis
gas phase synthesis method where flame heat is used to vaporise feedstock material and initiate the chemical reactions to produce **nanoparticle**s

[*Nanoparticles: An occupational hygiene review* [11]]

6.13
fluidized bed processing
fabricating or coating with another material while in a reactor that uses a suspension of particles in an upward flow of fluid (or downward flow if the particles are less dense than the fluid)

[PAS 71 Steering Group]

6.14
functionalization
attachment of chemical functional groups to a surface

[PAS 71 Steering Group]

6.15
furnace flow processing
method of **gas phase synthesis** that produces particles from a saturated vapour for substances having a high vapour pressure at intermediate temperatures

[PAS 71 Steering Group]

6.16
gas phase synthesis
all methods where the materials to be processed go through a gas phase; specifically a production method based on … nucleation of a supersaturated vapour and subsequent particle growth by condensation, **coagulation** and **coalescence**

[*Nanoparticles: An occupational hygiene review* [11]]

NOTE Examples include Physical Vapour Deposition (PVD) and Chemical Vapour Deposition (CVD) techniques.

6.17
high energy milling
form of **attrition** production that relies on the use of high levels of kinetic energy to break down material into finer and finer sizes

[PAS 71 Steering Group]

6.18
laser ablation processing
nanoparticle synthesis method using the energy from a (typically pulsed) laser to erode material from the surface of a target

[PAS 71 Steering Group]

6.19
laser pyrolysis
gas phase synthesis method where a flowing reactive gas is heated rapidly with a laser

[PAS 71 Steering Group]

6.20
mechanical alloying
alloying process that can be used to produce **nanomaterial**s, consisting of the repeated bonding, fracturing and rebonding of elemental and master alloy powders by highly energetic collisions in a mill under an inert atmosphere or vacuum

[PAS 71 Steering Group]

6.21
molecular self assembly
process that produces nanostructures by spontaneous aggregation into larger stable structures, driven by minimization of Gibbs free energy

[PAS 71 Steering Group]

6.22
plasma processing
method of **gas phase synthesis** using a plasma reactor to deliver the energy required to cause evaporation or initiate chemical reactions

NOTE The main types of plasma used are Direct Current (DC) plasma jet, DC arc plasma and Radio-Frequency (RF) induction plasma.

[PAS 71 Steering Group]

6.23
sol-gel processing
production process involving the conversion of a sol to a gel, which is then dessicated to produce particles

[PAS 71 Steering Group]

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6.24
solution phase templating
method for producing well defined structures in solution using **molecular self assembly** in conjunction with a template

[PAS 71 Steering Group]

6.25
sonochemistry
colloidal production method controlled by acoustic cavitation generating high temperatures and pressures within highly localized regions in the liquid, where molecular precursors undergo chemical reactions due to the application of ultrasound

[*Nanoparticles: An occupational hygiene review* [11]]

6.26
sonication
physical method to aid the dispersion of **nanoparticle**s in liquid by use of high-frequency sound waves

[PAS 71 Steering Group]

NOTE Also referred to as ultrasonic agitation and ultrasonication.

6.27
thermal spraying and coating
process for creating **nanoparticle**s and **nanostructured** coatings where a powder or wire is partially melted using gas or plasma flames and then deposited onto a surface to give a thin layer

[*Nanoparticles: An occupational hygiene review* [11]]

6.28
top-down processing
subtractive process for producing nanostructures from bulk materials

[PAS 71 Steering Group]

6.29
virus templating
production process using linear form of a virus as a structural template to direct the formation of inorganic **nanowires**

[Website of the American Chemistry Society [15]]

7 Production mechanisms

7.1
aerosol scavenging
removal of particles from the air by other particles through inertial, gravitational or diffusive processes

[PAS 71 Steering Group]

7.2
aggregation, orthokinetic
aggregation induced by hydrodynamic motions, such as stirring, sedimentation or convection

[*The Use of Nomenclature in Dispersion Science and Technology* [3]]

7.3
aggregation, perikinetic
aggregation induced by Brownian motion

[*The Use of Nomenclature in Dispersion Science and Technology* [3]]

7.4
cementation
binding together of particles by precipitation at their points of contact

[BS 2955:1993, *Glossary of terms relating to particle technology*]

7.5
coagulation
<of suspensions> specific type of **agglomeration** in which formation of **aggregates** is induced by the addition of an electrolyte to a suspension

[*The Use of Nomenclature in Dispersion Science and Technology* [3]]

7.6
coalescence
formation of homogeneous particles through the collision and subsequent merging or mixing of constituent material

[*Occupational Ultrafine Aerosol Exposure Characterization and Assessment* [1]]

7.7
deflocculation
breaking down of a floc

[BS 2955:1993, *Glossary of terms relating to particle technology*]

7.8
flocculation
aggregation of particles into a **floc**

[PAS 71 Steering Group]

7.9
granulation
process of combining particles into larger **agglomerate**s / granules

[BS 2955:1993, *Glossary of terms relating to particle technology*]

7.10
heterocoagulation
aggregation of dissimilar particles; in ceramic applications, the formation of **aggregate**s by the cohesion between particles of different materials (e.g. alumina and silica)

NOTE Also referred to as heteroagglomeration, heteroflocculation.

[*The Use of Nomenclature in Dispersion Science and Technology* [3]]

7.11
Ostwald ripening
growth of larger crystals from those of a smaller size that have a higher solubility than the larger ones

[*Compendium of Chemical Terminology* [3]]

7.12
solution precipitation
common type of chemical reaction in solution chemistry where two or more solutions are combined resulting in a reaction that produces an insoluble product or a precipitate

[PAS 71 Steering Group]

7.13
solvothermal reaction
chemical reaction or transformation in a solvent under supercritical conditions or near such a pressure–temperature domain

[*Journal of Materials Chemistry* [16]]

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8 Particle characteristics

8.1
adsorption surface area
surface area calculated from an adsorption method, e.g. **BET**

[BS 2955:1993, *Glossary of terms relating to particle technology*]

8.2
aspect ratio
ratio of the longest **Feret's diameter** of a particle to the shortest perpendicular

[Adapted from BS 2955:1993, *Glossary of terms relating to particle technology*, by PAS 71 Steering Group]

8.3
Average Agglomeration Number (AAN)
estimate of the degree of **agglomeration** in a suspension

[*The Use of Nomenclature in Dispersion Science and Technology* [5]]

8.4
BET surface area
surface area calculated from **BET analysis**

[BS 2955:1993, *Glossary of terms relating to particle technology*]

8.5
effective particle size
measure of particle size that characterizes its properties or behaviour in a specific system

[PAS 71 Steering Group]

8.6
Electrical Double Layer (EDL)
layer of ions at the solid/liquid interface in which two oppositely charged layers exist due to the attraction of counterions towards the interface by the surface charge

[PAS 71 Steering Group]

8.7
electrokinetic phenomena
<for phenomena including electrophoresis and electro-osmosis> effect where an applied electric field causes a relative motion between a charged surface or particle, and a continuous phase containing ions

<for phenomena including streaming and sedimentation potential> effect where an electrical potential is generated when a liquid containing ions is caused to flow past a charged surface or particle

NOTE The most familiar electrokinetic phenomena are electro-osmosis, streaming potential, electrophoresis and sedimentation potential.

[PAS 71 Steering Group]

8.8
elongation shape factor
ratio of the length of a rectangle with two sides parallel to the longest dimension of a particle to its width

NOTE See **aspect ratio**.

[BS 2955:1993, *Glossary of terms relating to particle technology*]

8.9
Fuchs surface area
<aerosols> surface area of an aerosol particle that interacts with the carrier gas and thus determines particle behaviour within the gas

[PAS 71 Steering Group]

8.10
Hamaker constant
<of particle interactions> material constant that measures the relative strength of the attractive van der Waals forces between two surfaces

[*The Use of Nomenclature in Dispersion Science and Technology* [5]]

8.11
Point of Zero Charge (PZC)
pH at which the negative and positive charges are balanced, so there is no net charge on the colloid

[*Introduction to modern colloid science* [19], p 22]

NOTE May also apply to non-colloids.

8.12
specific surface area
ratio of the surface area to the mass of a **nanopowder**

[PAS 71 Steering Group]

8.13
zeta potential
electrostatic potential at the slipping plane (which marks the region where the liquid molecules surrounding the particle first begin to move with respect to the surface) relative to the potential in the bulk solution

[*Introduction to modern colloid science* [19], p 22]

9 Particle volume and diameter

9.1
aerodynamic diameter
diameter of a spherical particle with a density of 1 000 kg/m^3, that has the same settling velocity as the particle under consideration; related to the inertial properties of **aerosol** particles

[*Occupational Ultrafine Aerosol Exposure Characterization and Assessment* [2]]

NOTE 1 Generally used to describe particles or agglomerates larger than 300 nm – 500 nm (where the actual size depends on the densities of the particle and the medium).

NOTE 2 See **equivalent diameter**.

9.2
envelope volume
volume of a particle such as would be obtained by tightly shrinking a film to contain it

[PAS 71 Steering Group, adapted from BS 2955:1993, *Glossary of terms relating to particle technology*]

9.3
equivalent diameter
diameter of a sphere which behaves like the observed particle relative to or deduced from a chosen property

[BS 2955:1993, *Glossary of terms relating to particle technology*]

NOTE Different properties include **aerodynamic**, diffusion, **hydrodynamic**, **mobility**, perimeter, surface and volume.

9.4
Feret's diameter
distance between two parallel tangents on opposite sides of the image of a particle

NOTE Used to calculate the **aspect ratio** of a particle.

[BS 2955:1993, *Glossary of terms relating to particle technology*]

9.5
hydrodynamic diameter (cumulants mean)
effective diameter of a particle in a liquid environment

NOTE 1 The hydrodynamic diameter measured by dynamic light scattering is referred to as the Z-average mean.

NOTE 2 See **equivalent diameter**.

[PAS 71 Steering Group]

9.6
isometric particle
particle with the same measurement in three dimensions

[BS 2955:1993, *Glossary of terms relating to particle technology*]

9.7
mobility diameter
diameter of a spherical particle with the same mobility as the particle under consideration

NOTE 1 The particle is generally smaller than 300 nm – 500 nm in diameter, the actual size depending on the densities of the particle and the medium.

[*Occupational Ultrafine Aerosol Exposure Characterization and Assessment* [2]]

NOTE 2 See **equivalent diameter**.

9.8
particle size
size of a particle as determined by a specified measurement method

NOTE See the introduction to this PAS.

[PAS 71 Steering Group]

10 Measurement and analysis techniques

10.1
aerosol diffusion charging
method in which the Fuchs surface area of an aerosol is measured directly, by passing electrically neutral particles through a unipolar ion cloud and measuring the resulting aerosol charge

NOTE When the charging rate is low, aerosol charge is proportional to the Fuchs surface area.

[PAS 71 Steering Group]

10.2
Atomic Force Microscopy (AFM)
technique for imaging surfaces by mechanically scanning their surface contours using a microfabricated probe, in which the deflection of a sharp tip sensing the surface forces, mounted on a soft cantilever, is monitored as the tip is moved across the surface

NOTE Part of the family of microscopies referred to as **Scanning Probe Microscopy** (SPM).

[PAS 71 Steering Group]

10.3
Auger Electron Spectroscopy (AES)
technique in which an electron spectrometer is used to measure the energy distribution of Auger electrons emitted from a surface

NOTE AES instruments can achieve lateral resolutions as low as 5 nm.

[BS ISO 18115, *Surface chemical analysis — Vocabulary*]

10.4
BET analysis
characterization technique based on the model developed by Brunauer, Emmet and Teller that allows the surface area of powders to be determined by gas adsorption

NOTE Typically nitrogen or carbon dioxide is used but gases such as krypton or argon may be used for low surface area materials because of their greater sensitivity (mass gain per unit area).

[PAS 71 Steering Group]

10.5
coincidence
detection of two or more particles as a single particle

[BS 2955:1993 and *Particle Size Characterization* [4]]

10.6
Condensation Particle Counter (CPC)
most widely used type of instrument for detecting and counting **nanoparticle aerosol**s, which operates by condensing vapour onto sampled ultrafine particles to grow them to a size range that can be detected by a standard optical counter

[*Nanoparticles: An occupational hygiene review* [11]]

10.7
Differential Mobility Analysis (DMA)
method of establishing the size distribution of aerosols, based on the principle of the mobility of a charged particle in an electric field

[PAS 71 Steering Group]

10.8
Electron Energy Loss Spectroscopy (EELS)
technique where inelastic interaction of an electron beam with atoms in a sample results in an energy distribution spectrum that contains compositional and chemical bonding information

[PAS 71 Steering Group]

10.9
Electron Probe MicroAnalysis (EPMA)
spatially-resolved elemental analysis based upon electron-excited x-ray spectrometry with a focused electron probe and an electron interaction volume with micrometer to sub-micrometer dimensions

[ISO/DIS 23833, *Microbeam analysis — Electron probe microanalysis (EPMA) — Vocabulary*]

NOTE Covers both Wavelength Dispersion Spectrometry (WDS) and Energy Dispersion Spectrometry (EDS).

10.10
epiphaniometer
instrument used to measure the Fuchs surface area of **aerosol**s directly: the **aerosol** is passed through a charging chamber where lead isotopes created from a decaying actinium source are attached to the particle surfaces; the particles are transported through a capillary to a collecting filter; the amount of radioactivity measured is proportional to the particle surface area

[Adapted from *Nanoparticles: An occupational hygiene review* [11] by PAS 71 Steering Group]

10.11
Field Flow Fractionation (FFF)
method of separating particles in a fluid flowing in a channel by applying a field perpendicular to the flow, e.g. a transverse flow or thermal field

[PAS 71 Steering Group]

10.12
Glow Discharge Mass Spectrometry (GDMS)
method in which a mass spectrometer is used to measure the mass-to-charge quotient and abundance of ions from a glow discharge generated at a surface

[BS ISO 18115, *Surface chemical analysis — Vocabulary*]

NOTE See also **Glow Discharge Spectrometry**.

10.13
Glow Discharge Optical Emission Spectrometry (GDOES)
method in which an optical emission spectrometer is used to measure the wavelength and intensity of light emitted from a glow discharge generated at a surface

[BS ISO 18115, *Surface chemical analysis — Vocabulary*]

NOTE See also **Glow Discharge Spectrometry**.

10.14
Glow Discharge Spectrometry (GDS)
method in which a spectrometer is used to measure relevant intensities emitted from a glow discharge generated at a surface

NOTE This is a general term which encompasses **GDOES** and **GDMS**.

[BS ISO 18115, *Surface chemical analysis — Vocabulary*]

10.15
halo
dark or light false perimeter of a particle image

[*Particle Size Characterization* [4]]

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10.16
Ion Beam Analysis (IBA)
method to elucidate composition and structure of the outermost atomic layers of a solid material, in which principally monoenergetic, singly-charged probe ions, scattered from the surface, are detected and recorded as a function of their energy or angle of scattering, or both

NOTE LEISS, MEISS and RBS are all forms of IBA in which the probe ion energies are typically in the ranges 0,1 keV to 10 keV, 100 keV to 200 keV and 1 MeV to 2 MeV, respectively. These classifications represent three ranges in which fundamentally different physics is involved.

[BS ISO 18115, *Surface chemical analysis — Vocabulary*]

10.17
isoelectric point (IEP)
pH at which dispersed particles show no electrophoretic mobility and the **zeta potential** has a value of zero

[*The Use of Nomenclature in Dispersion Science and Technology* [5]]

10.18
isoionic point
pH of a solution at which a particle or molecule contains as many negative charges as positive charges

[PAS 71 Steering Group]

10.19
Near Field Scanning Optical Microscopy (NSOM)
technique for imaging surfaces in transmission or reflection by mechanically scanning an optical probe much smaller than the wavelength of light over the surface whilst monitoring the transmitted or reflected light

NOTE 1 Also referred to as Scanning Near Field Optical Microscopy (SNOM).

NOTE 2 Part of the family of microscopies referred to as **Scanning Probe Microscopy** (SPM).

[PAS 71 Steering Group]

10.20
PhotoEmission Electron Microscopy (PEEM)
technique that involves shining linearly or circularly polarized X-rays onto the sample surface, allowing the distribution of electrons emitted from the surface to be imaged

NOTE Has particular applications in magnetic domain imaging; allows the user to derive all three components of magnetization.

[PAS 71 Steering Group]

10.21
Photon Correlation Spectroscopy (PCS)
method of measuring diffusion diameter from Brownian motion

[PAS 71 Steering Group]

NOTE Also referred to as Dynamic Light Scattering (DLS) and quasi-electric or self-beat light scattering.

10.22
Raman effect
scattering of light with a change in frequency characteristic of the scattering substance, representing a change in the vibrational, rotational, or electronic energy of the substance that can be used to give information on its chemical bonding or mechanical stress state

[PAS 71 Steering Group]

10.23
Raman spectroscopy
spectroscopy in which the **Raman effect** is used to investigate molecular energy levels

[OED [20]]

10.24
Selective Area Electron Diffraction (SAED)
diffraction of electrons from an area of the sample selected by an aperture

[PAS 71 Steering Group]

10.25
Scanning Electron Microscopy (SEM)
technique that produces magnified images of a specimen by scanning its surface with an electron beam

NOTE 1 SEMs typically have a spatial resolution of 1 to 10 nm.

NOTE 2 The instruments may be used to obtain the size, shape, structure and, in some cases, compositional information from single or collections of particles.

NOTE 3 Some instruments have added detectors, such as an energy dispersive detector, that allow the composition of the sample to be determined with spatial resolutions below 1 μm, channelling detectors that allow crystal orientations or strain to be measured, or backscatter detectors that provide atomic contrast.

[PAS 71 Steering Group]

10.26
Scanning Mobility Particle Sizing (SMPS)
technique for detecting and counting **nanoparticle**s, which gives both size and number information, and is capable of measuring **aerosol** size distribution from 3 to 800 nm; operates by charging particles and separating them based on their mobility when passing between electrodes

NOTE 1 The size distribution is expressed in terms of particle mobility diameter.

[*Nanoparticles: An occupational hygiene review* [11]]

10.27
Scanning Probe Microscopy (SPM)
family of techniques for imaging a surface, using the interaction of a physical probe with the surface

NOTE See also **AFM**, **STM** and **NSOM**.

[PAS 71 Steering Group]

10.28
Scanning Tunnelling Microscopy (STM)
technique for revealing the apparent electron-density-related atomic structure of surfaces, using a needle-like probe near the object under observation; a tunnelling current, which is measured, is generated by altering the potential at the tip of the probe; a 3D representation of the sample surface is generated by rastering the surface of the object and mapping the distance for constant current level at various points

NOTE STMs have also been used to produce changes in the molecular composition of substances.

[PAS 71 Steering Group]

10.29
Secondary Ion Mass Spectrometry (SIMS)
method in which a mass spectrometer is used to measure the mass-to-charge quotient and abundance of secondary ions emitted from a sample as a result of bombardment by energetic ions

NOTE SIMS is, by convention, generally classified as dynamic, in which the material surface layers are continually removed as they are being measured, and static, in which the ion areic dose during measurement is restricted to less than 10^{16} ions/m^2 in order to retain the surface in an essentially undamaged state.

[BS ISO 18115, *Surface chemical analysis — Vocabulary*]

10.30
Small Angle Neutron Scattering (SANS)
technique for measuring the scattering of neutrons at small angles with respect to the incident beam

NOTE May be used to determine the spatial distribution of adsorbed species on a particle.

[PAS 71 Steering Group]

10.31
Total Reflection X-Ray Fluorescence Spectroscopy (TXRF)

method in which an X-ray spectrometer is used to measure the energy distribution of fluorescence X-rays emitted from a surface irradiated by primary X-rays under the condition of total reflection

[BS ISO 18115, *Surface chemical analysis — Vocabulary*]

10.32
Transmission Electron Microscopy (TEM)

technique using electrons that can image through very thin samples in transmission or, for thicker samples, the outline profile in projection

NOTE 1 TEM typically requires samples 100 to 200 nm thick if internal details are required. Thicker samples may be viewed with higher energies such as 200 or 300 keV electron beams.

NOTE 2 TEM can be used to image lattice planes and individual points with resolutions better than 0.2 nm.

[PAS 71 Steering Group]

10.33
Ultra-Violet Photoelectron Spectroscopy (UPS)

method in which an electron spectrometer is used to measure the energy distribution of photoelectrons emitted from a surface irradiated by ultra-violet photons

[BS ISO 18115, *Surface chemical analysis — Vocabulary*]

10.34
X-Ray Diffraction Line Broadening (XRDLB)

technique for measuring the size and strain of individual crystals under about 0.1 μm, where the Debye rings (X-ray lines) generated by the procedure are broadened

NOTE Strain in the material may also cause X-ray line broadening.

[PAS 71 Steering Group]

10.35
X-ray Photoelectron Spectroscopy (XPS)

method in which an electron spectrometer is used to measure the energy distribution of Auger and photoelectrons emitted from a surface irradiated by X-ray photons

NOTE XPS instruments can achieve a lateral resolution as low as 5 μm.

[BS ISO 18115, *Surface chemical analysis — Vocabulary*]

11 Abbreviations

AES	Auger Electron Spectroscopy
AFM	Atomic Force Microscopy
AIM	Atomic Imaging and Manipulation
ALE	Atomic Layer Epitaxy
ATM	Asynchronous transmission mode
ATOFMS	Aerodynamic Time Of Flight Mass Spectrometer
BCC	Body-Centred Cubic
BEEM	Ballistic Electron Emission Microscopy
BET	Brunauer, Emmett and Teller method of measuring surface area
BSEI	Backscattered Electron Image
Cermet	Ceramic-Metal Composite
CFU	Colony Forming Units
CMOS	Complementary Metal-Oxide Semiconductor
CMP	Chemical Mechanical Polishing
CNT	Carbon NanoTube
CPC	Condensation Particle Counter

CVD	Chemical Vapour Deposition
DFT	Density Functional Theory
DMA	Differential Mobility Analyzer
EDS	Energy Dispersive Spectrometry
EDX	Energy Dispersive X-ray analysis
EDX	Energy Dispersive X-ray Spectrometry
EELS	Electron Energy Loss Spectroscopy
EHDA	Electrohydrodynamic Atomization
EIA	Energetic Ion Analysis
ELPI	Electrical Low Pressure Impactor
EPMA	Electron Probe MicroAnalysis/Analyzer
ESAVD	Electrostatic Spray Assisted Vapour Deposition
ESCA	Electron Spectroscopy for Chemical Analysis
ESEM	Environmental Scanning Electron Microscope
EUV	Extreme Ultra-Violet
EXAFS	Extended X-ray Absorption Fine Structure
FABMS	Fast Atom Bombardment Mass Spectroscopy
FCC	Face-Centred Cubic
FDA	Force Discrimination Assay
FEG-SEM	Field Emission Gun Scanning Electron Microscope
FEL	Free Electron Laser
FET	Field-Effect Transistor
FRET	Fluorescence Resonance Energy Transfer
FWHM	Full Width, Half Maximum
GDS	Glow Discharge Spectrometry
GDOES	Glow Discharge Optical Emission Spectrometry
GDMS	Glow Discharge Mass Spectrometry
GMR	Giant Magneto-Resistance
GSD	Geometric Standard Deviation
HDS	HydroDeSulfurization
HEISS	High Energy Ion Scattering Spectrometry
HFET	Heterojunction Field-Effect Transistor
HREELS	High-Resolution Electron Energy Loss Spectroscopy
HREM	High-Resolution Electron Microscopy
HVOF	High Velocity Oxygen Fuel
IBA	Ion Beam Analysis
IEP	IsoElectric Point
IFLM	Inorganic Fullerene-Like Materials
IHP	Inner Helmholtz Plane
IP	Ionization Potential
LEISS	Low Energy Ion Scattering Spectrometry
LFM	Lateral Force Microscopy
LISA	Lithographically Induced Self-Assembly
MBE	Molecular Beam Epitaxy
MD	Molecular Dynamics
MEISS	Medium Energy Ion Scattering Spectrometry
MEMS	MicroElectroMechanical Systems

MFM	Magnetic Force Microscopy
MMAD	Mass Median Aerodynamic Diameter
MRM	Magnetic Resonance Microscopy
MS	Mass Spectrometry
micro-TAS	micro(scale)-Total Analysis System
nano-TAS	nano(scale)-Total Analysis System
MWNT	Multi-Walled NanoTube
NCSL	NanoCrystal Super Lattices
NDR	Negative Differential Resistance
NEMS	NanoElectroMechanical Systems
NIL	NanoImprint Lithography
nM	nanoManipulator
NMR	Nuclear Magnetic Resonance
NQR	Nuclear Quadrupole Resonance
NSOM	Near-field Scanning Optical Microscopy
OHP	Outer Helmholtz Plane
OPC	Optical Particle Counter
OMPVE	OrganoMetallic Vapour Phase Epitaxy
PEELS	Parallel Electron Energy Loss Spectroscopy
PEEM	PhotoEmission Electron Microscopy
PVS	Physical Vapour Synthesis
PZC	Point of Zero Charge
QCA	Quantum Cellular Automata
QMOS	Quantum Metal Oxide Semiconductor
RBS	Rutherford Backscattering Spectrometry
RTD	Resonant Tunnelling Diode
SAM	Self-Assembled Monolayer
SAM	Scanning Auger Microscope
SAMMS	Self-Assembled Monolayers on Mesoporous Supports
SCM	Scanning Capacitance Microscopy
SECM	Scanning ElectroChemical Microscopy
SEED	Self-Electro-optic Effect Device
SEI	Secondary Electron Image
SEM	Scanning Electron Microscope
SET	Single Electron Transistor
SFA	Surface Force Apparatus
SFM	Scanning Force Microscope
SIMS	Secondary Ion Mass Spectrometry
SMPS	Scanning Mobility Particle Sizer
SNMS	Secondary Neutral Mass Spectrometry
SNMS	Sputtered Neutral Mass Spectrometry
SPM	Scanning Probe Microscopy
STEM	Scanning Transmission Electron Microscope
STM	Scanning Tunnelling Microscope
STS	Scanning Tunnelling Spectroscopy
SWCNT	Single-Walled Carbon NanoTube
SWNT	Single-Wall NanoTube

TDM	Two Dimensional Material
TEM	Transmission Electron Microscope
TEOM®	Tapered Element Oscillating Microbalance
TOFMS	Time Of Flight Mass Spectrometry
TXRF	Total Reflection X-ray Fluorescence Spectroscopy
UPS	UltraViolet Photoelectron Spectroscopy
UV/VIS	UltraViolet/VISible light
VCSEL	Vertical Cavity Surface Emitting Laser
WDS	Wavelength Dispersive Spectrometry
WDX	Wavelength Dispersive X-ray Spectrometry
XMCD	X-ray Magnetic Circular Dicroism
XPS	X-ray Photoelectron Spectroscopy

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